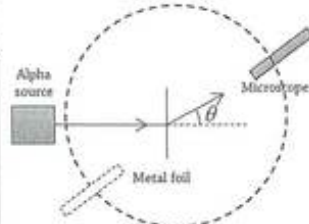


Rutherford scattering

Rutherford's scattering experiment in 1908 provided new evidence about the structure of the atom and resulted in the scientific community moving on from J J Thomson's plum pudding model of the atom and adopting Rutherford's model.

The experiment

- An alpha source provided a beam of alpha particles that were aimed at a thin piece of gold foil.
- All alpha particles (positively charged) were of the same energy and the experiment was carried out in an evacuated chamber.
- The alpha particles were detected by a detector that remained at a fixed radial distance from the point of collision between the particles and the foil.
- Light was emitted when the particles hit the detector and these emissions of light could be seen by a microscope.



The results

- A small portion of alpha particles were deflected by the foil through angles greater than 90°.
- The majority of alpha particles passed through the foil, some with no deflection and some with a small angle of deflection.

The conclusions

- The majority of particles passed through the foil, which shows that the atoms making up the foil are likely mostly empty space. Most of the mass of the atom is concentrated in a small nucleus at the centre of the atom.
- Some alpha particles were deflected, which suggests that the nucleus must be positively charged, as the positively charged alpha particles were repelled as they approached the nucleus.

Radioactivity

Alpha, beta and gamma radiation

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Type of radiation	Consists of	Range in air	Ionisation	Absorption	Applications
Alpha	Two protons + two neutrons	<10 cm	Creates around 10 ⁴ ions per cm in air	Stopped by thin metal foil or paper	Thickness measurements of paper Used in smoke detectors
Beta	Electron or positron	<1 m	Creates around 100 ions per mm in air	Stopped by 3-5 mm of aluminium	Thickness measurements of aluminium foil
Gamma	Photon of energy	Obeys inverse square law (1/r ²)	Weakly ionising	Stopped by several cm of lead	Used in medicine to image internal structure of the body

Medicine

- The effects of radiation can be harnessed to benefit patients in the field of medicine, with treatments such as radiotherapy.
- However, the risks of radiation exposure, such as burns, cell damage and cancer are still present and medical staff will continuously have to use clinical judgement to assess the therapeutic ratio: the benefits compared to the potential risks.

Inverse square law (γ radiation)

$$I = \frac{k}{x^2}$$

I = intensity
 x = distance from source
 k = constant of proportionality

Intensity of radiation obeys the inverse square law, so that intensity decreases with distance. This can be verified experimentally by using a gamma source and a Geiger Muller tube to measure the intensity of the radiation detected at distance x .



Background radiation

- A low level of radiation is always around us, from both natural and man-made sources of radiation.
- Sources of background radiation:
Natural: Nuclear materials in ground, cosmic rays
Man-made: Buildings, nuclear power plants, medical nuclear applications
- When calculating the amount of radioactivity present due to a source it is important, therefore, that the background radiation is measured first and that this value is taken away from the radioactivity measured when the source is present.



Radioactive decay

Radioactive decay occurs when an atom is unstable, and emits radiation to obtain a more stable state.

Radioactive decay is a random process. This means that we can't know which nucleus in a sample will decay next, or when.

Activity, A:

the number of unstable nuclei that decay per second in a given sample:

$$A = A_0 e^{-\lambda t}$$

$$A = \lambda N$$

Decay probability:

$$\frac{\Delta N}{\Delta t} = -\lambda N$$

Number of unstable nuclei:

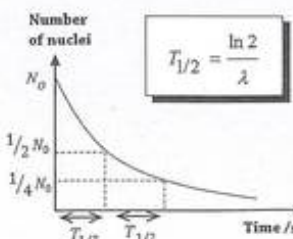
$$N = N_0 e^{-\lambda t}$$

N = number of atoms in sample
 N_0 = initial number of atoms in sample
 λ = decay constant
 t = time

The half-life ($T_{1/2}$) of a radioactive substance is the amount of time it takes for the activity of the substance to decrease to half its original value. Half-life is a constant, no matter the amount of substance left.

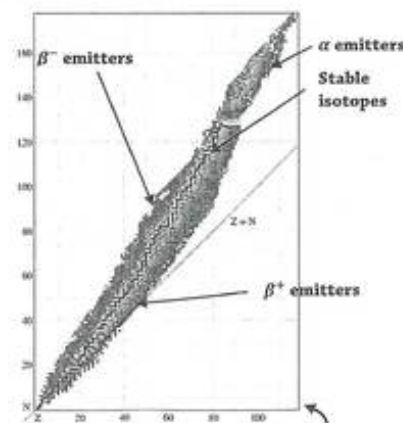
Half-life is used in medicine to determine which isotope to use to image inside a patient's body as the source needs only to be radioactive as long as the imaging takes and then should have as little radioactivity as possible.

It is also used in areas such as carbon dating. All living organisms have a roughly equal ratio of ¹²C to ¹⁴C in their bodies. When they die, the ¹⁴C slowly decays. By examining the amount of ¹⁴C left in a sample, its age can be determined.

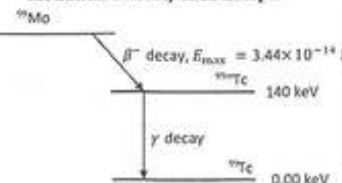


$$T_{1/2} = \frac{\ln 2}{\lambda}$$

Nuclear stability

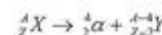


A plot of neutron number N against proton number Z is a useful means of determining the nuclear stability of an isotope.

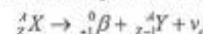


Decay modes

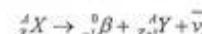
α emission: An alpha particle is emitted from the parent nucleus to leave behind a daughter nucleus.



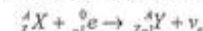
β⁺ emission: A positron is emitted from the parent nucleus to leave behind a daughter nucleus. An electron neutrino is emitted as a proton in the nucleus changes into a neutron.



β⁻ emission: An electron is emitted from a parent nucleus to leave behind a daughter nucleus. An antineutrino is emitted as a neutron in the nucleus changes into a proton.



Electron capture: An inner shell electron is captured by a proton-rich nucleus and a proton changes into a neutron. An electron neutrino is also emitted.



Nuclear energy levels

- When an unstable nucleus undergoes any of these decays it will emit gamma radiation.
- The emission of gamma radiation will result in the nucleus losing energy, the nucleus will move from an excited state to its ground state by moving down through its lower energy states.
- The application of gamma ray emission can be seen in medical imaging.
- Technetium-99m is an isotope that is used in the field of medical diagnostics to monitor blood flow and to image patients using a gamma camera, which images internal structures by detecting gamma radiation emitted from a technetium tracer placed in the body.